Bio-Oil
Commercialization Plan

Prepared for the
NH Office of Energy and
Planning

by

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Introduction

I. Commercialization Plan Summary†

A. There is a need for an expanded use of low-grade wood chips in the North Country of New Hampshire.[1a,1b,2]

B. One alternative is the conversion of wood chips into bio-oil, an environmentally friendly, renewable energy source.

C. The objective of this study is to evaluate the economic viability of locating a bio-oil facility in New Hampshire as an alternative use of wood chips, and to inform interested parties as to the current state of bio-oil technology. Contractual requirements for developing this commercialization plan specifically forbid the selection of and /or bias towards any one producer or process. Therefore, a specific process, management structure, ownership scenario, plant location, etc. could not be identified; thus specific detailed cost analysis as normally found in a commercialization plan was not possible. Rather, average representative costs consistent with published industry data were used. The next step in locating a commercial bio-oil facility in New Hampshire would be to select a vendor of choice and work with that organization to produce a detailed business plan identifying management, ownership structure, process parameters, products and market analysis sufficient for attracting adequate financing. It is assumed in this initial modeling that the resulting entity would be a public/private partnership with financing from the partners, local investors, commercial institutions and local government.

D. Bio-oil technology is in the early stage of development; however, one company has commercial plants in operation[3] *and two other companies are seeking funding to build commercial facilities.*[4,5]

E. A 100-ton per day (tpd) plant operating at 90% efficiency using dried wood chips containing 8% moisture content by weight would consume approximately 46,000 tons of green wood chips per year having a 38% average moisture content by weight. Such a plant would generate approximately 4.8 million gallons of bio-oil having the heat equivalent (BTU) of 2.64 million gallons of #2 fuel oil.

F. The heat content of bio-oil (75,500 BTU per gallon) is only 55% that of #2 fuel oil.‡ *Therefore one must burn 1.82 gallons of bio-oil to obtain the same amount of heat as released when burning one gallon of #2 fuel oil. At the current price of #2 fuel oil, $0.86 per gallon in tank car quantities, the equivalent cost of bio-oil would be $0.47 per gallon. For bio-oil to be cost competitive with #2 fuel oil on an equal*

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† *In this document all units of weight are reported in English Units (eg.1 ton equals 2000 lbs) and all currencies are reported in US $'s unless specifically stated otherwise.*

‡ *For this study it was assumed that the market for bio-oil would be small to medium sized industrial boilers burning #2 fuel oil, not residential customers. However, during the course of this study it became apparent that an alternative market would be larger industrial boilers burning #6 fuel oil. For comparison, bio-oil has a 49% lower heat content or an equivalent price of $0.39 as compared to a market price of $0.80 per gallon for #6 oil in truckload quantities at Portsmouth, NH in late June 2004.*

energy basis the selling price of bio-oil must be less than or equal to $0.47 per gallon. This compares to a break-even production cost for bio-oil of $0.71 per gallon or a net loss of approximately $0.24 per gallon for a stand-alone facility. In smaller quantities the price of #2 fuel oil ranges from $1.10 to $1.29 per gallon or an equivalent cost for bio-oil of $0.60 to $0.71 per gallon.

G. An alternative scenario for reducing the production cost of bio-oil would be to co-locate a bio-oil facility with an existing wood fired power plant. Utilization of waste heat along with cost sharing of facilities and labor would reduce the production price per gallon of bio-oil to approximately $0.55 per gallon. Thus by selling to a mix of customers a competitive price might be achieved.

H. A second alternative and profitable scenario would be to operate a bio-refinery where higher value added products would be extracted and sold in addition to selling the residual bio-oil. This approach is similar to that used in existing commercial plants.[3]

I. The most attractive option for New Hampshire would be the co-location of a bio-refinery with an existing facility such as a wood fired power plant. This configuration would provide the maximum profit and return on investment (ROI) for investors. Selling bio-oil at $0.55 a gallon, char at $47 per ton and refined chemicals at an average price of $0.97per pound would provide a profit with 20% return on investment.

J. Therefore, it can be concluded that there are certain operating scenarios in which a bio-oil facility located in New Hampshire, using low-grade wood chips as a feedstock, might be economically viable.

II. Risk Factors

A. Assumptions: Assumptions used in this report are based on the best currently available knowledge of bio-oil technology and business conditions as they currently exist in Northern New Hampshire. It is understood that assumptions may change based on differences relevant to proprietary technology and conditions unique to specific business groups and/or locations.

B. Critical Factors: Critical factors used in the economic analysis such as feedstock moisture content, bio-oil yield, capital cost, return on investment, overhead rates and etc. are consistent with those currently being used in northern New Hampshire at the time of writing. These parameters may change with time, location and/or readers may wish to use parameters more to their liking. If so, the accompanying spreadsheet may be used to change these parameters to assess their impact on the overall economic analysis.

C. Emerging Technology: The production of bio-oil from the fast pyrolysis of wood chips is in the early stages of development. There is no assurance that this technology will emerge as a significant source of alternative fuels and/or become an expanded source for value-added chemicals.

D. Feedstock Availability: There is no assurance that existing markets for wood chips will not grow and/or that alternative uses of wood chips will not be found. A competitive market for wood chips could result in a price increase, thus making the production of bio-oil economically impractical.

E. Limited Access to Technology: To date there are only three companies in North America capable of supplying the required technology. Only one of these companies has demonstrated the ability to establish a commercial plant. There is no assurance that any of these companies are interested in building a plant in New Hampshire. There is no assurance that a viable business agreement can be reached with any of the potential suppliers.

F. Limited Source of Information: Much of the information necessary to establish a commercial plant is retained as proprietary information. There is no public information available to validate and/or contradict many of the assumptions made in this study. There are no existing stand-alone commercial plants. Existing commercial plants are an integrated part of other commercial processes and most, if not all, products generated by the plant are consumed onsite. Operating and financial information is retained as proprietary information. Much of the information provided in this report was obtained from private conversations and presentations made by the potential suppliers, "knowledgeable third party sources" and/or from academic studies.

G. Limited Market: To date sufficient quantities of bio-oil have not been available to establish a market. There is no assurance that a viable market will emerge. To use bio-oil as an alternative fuel, customers will need to invest time and money into converting boilers to burn bio-oil. New value-added chemicals will need to compete with existing sources. Barriers to market entry are unknown and could be significant. It is uncertain how current market suppliers will react, e.g., reduce prices in an effort to eliminate competition.

H. Permits / Licensing: There has been no attempt to acquire the required local, state and federal permits and licenses necessary to operate a bio-oil plant and/or to utilize the products generated. A plant site has not been identified. This report relies on the fact that commercial plants exist in other U.S. States and in Canada. These plants have received the necessary permits without issue. There are also technical papers reporting the physical properties of bio-oil, as well as plant emissions.

I. Energy Credits: Various State and Federal Agencies have enacted and/or proposed legislation to provide energy credits for specific applications. It is not certain that these credits will be enacted and/or if they are, will be applicable to a bio-oil facility using currently available technology. For purposes of this report <u>no</u> benefits related to energy credits are assumed.

III. Capitalization

A. Capital requirements for a stand-alone bio-oil facility or a bio-refinery would be approximately $7.8MM and $10.55MM respectively. The use of capital would be as follows:

Utilization	Stand Alone	Bio-Refinery
Capital Equipment	$ 2,500,000	$ 3,500,000
Construction / Installation Cost	$ 3,100,000	$ 4,100,000
Commissioning @ 6 mths	$ 1,500,000	$ 2,100,000
Working Capital	$ 700,000	$ 850,000
Total Capital Needs	$ 7,800,000	$ 10,550,000

Table I. Capital Utilization

B. Sources of capital would be as follows:

Source of Funds	Stand-Alone	Bio-Refinery
1. Equity Investment		
a. Investors Equity	$ 1,100,000	$ 1,500,000
b. CDBG Grant for 16 employees @ $20K per employee	$ 320,000	$ 320,000
2. Sale of Product generated during commissioning	$ 280,000	$ 380,000
3. Bank Financing		
a. Capital Equipment Loan	$ 2,500,000	$ 3,500,000
b. Construction Loan	$ 3,100,000	$ 4,100,000
c. Draw on Line of Credit @ 80% Receivables, 20% Inventory	$ 500,000	$ 750,000
Total Funds Available	$ 7,800,000	$ 10,550,000

Table II. Source of Funds

Commercialization Plan

I. Importance of Markets for Low-Grade Wood[6]

A. The timber industry is important to NH since the state is one of the most heavily forested in the nation.

B. NH forests are primarily privately owned and owners rely on income from the harvesting of these woodlots.

C. NH Division of Forest and Lands show that between 37% and 44% of all standing timber in state is considered low-grade.

D. Low-grade means it does not meet the specification for saw logs used for lumber or veneer. 20-80% of the volume of wood harvested during a logging job is considered low-grade. From April 1, 2001 to March 31, 2002 sixty percent of volume of wood harvested in NH was low-grade. Percentage varied by county with a low of 41% in Cheshire County and a high of 69% in Grafton County. In 2001 NH generated 892,000 tons of wood chips and a total of more than 2,000,000 tons of low-grade wood total.

E. Low-grade markets are pulpwood (primarily used in paper manufacture), whole-tree chips used to generate electricity and fuel wood primarily for home heating.

F. Forests also provide wildlife habitat and open space for camping, hiking, etc.

G. State Forester Philip Bryce in testimony before the NH legislature in 2003 stated "Markets for low-grade wood are essential to the practice of sustainable forestry…Without adequate markets for low-grade wood, there will be limited opportunity to maintain and improve the quality of timber upon which our forest products industry depends."[7]

H. Sawmills also rely on low-grade wood markets as an outlet for mill residue. It is estimated that in 2000 NH sawmills produced over 300,000 tons of mill residue annually.

I. Whole tree chips represented 25% of wood harvested in NH in 2001 and used in wood-fired power plants. In 2002 power plants provided a market for 1.14 million tons of whole tree chips. BioEnergy closed in 2002 (140,000 tons annually) and Whitefield Power & Light was scheduled to close in 2003 (180,000 tons annually).[†] By 2009 the rate orders for all wood fired plants will terminate and it is possible that all wood fired power plants could close unless there is a significant change in the competitive nature of the market for electricity.

J. Another major market is pulpwood for the paper industry. NH has two significant in-state mills. Because of cutbacks and closing of mills the pulpwood

[†] The owners of Whitefield Power & Light have entered into preliminary agreements with a buyer to purchase the power plant with the understanding that the plant will remain in operation. The final sale of the plant and thus the continued operation of the plant remain uncertain.

market has decreased from 1,375,000 tons in 1997 to less than 1,000,000 tons in 2001.

K. Conclusion: To sustain an active forest industry in NH an alternative market for low-grade wood is needed.

II. What is Bio-oil?

Physical properties of bio-oil produced from wood have been presented in numerous publications and are summarized as follows:[8-15]

A. Bio-oil is an organic liquid fuel produced from the fast pyrolysis of low-grade wood. In addition to bio-oil, a high quality char and a combustible gas are produced at approximately 70%, 17% and 13% respectively.

B. The bio-oil production process is described as closed loop (i.e. self contained).

C. Bio-oil is not a petroleum-based product and is insoluble in petroleum-based materials such as #2 fuel oil or gasoline.

D. Bio-oil contains approximately 30% water and has a lower hydrocarbon content than petroleum based fuels, thus having a lower heat content approximately 55% that of light fuel oil or diesel and approximately 90% of ethanol.

E. Bio-oil is a transportable liquid similar in properties to petroleum-based fuels. Its viscosity is between that of #2 and #6 fuel oil. Similar to diesel, it has a limited shelf life. This can be extended by storing at room temperature, in a closed container with periodic stirring and/or agitation.

F. It is slightly more acidic (pH of 2.5 – 3) than petroleum based products and should be stored and handled using stainless steel and or polyethylene containers.

G. Limited studies to date indicate that bio-oil is no more hazardous than similar petroleum-based materials and should be handled using similar precautions.[16]

H. Bio-oil is produced from biomass, a renewable resource, and as such can be marketed as a Green Product.

I. Combustion of bio-oil is CO_2 neutral.

J. Extensive burner studies that have been performed with bio-oil generated from wood feedstock show the following:[17-22]

1. To maintain an energy release rate equivalent to that for petroleum-based fuels requires a greater flow rate approximately 1.6 times that for #2 fuel oil.
2. Typical combustion parameters include an air atomizing burner and a fuel handling system similar to that used for emulsified bitumen. Biofuel[†] is stored in a tank with the temperature maintained at about

[†] Certain published documents refer to bio-oil as "biofuel". For this report when a reference is made to biofuel it should be considered to mean bio-oil. It is understood that the term biofuel has a much broader meaning than bio-oil.

$36^{o}C$ and a blade impeller mixer to keep the fuel homogenized. Fuel is transported to the burner using a positive displacement pump and an in-line steam heat exchanger is used to obtain increased uniform fuel temperatures at the burner. Nominally preheated atomizing air (114^{o} to $132^{o}C$) is used and flue gas oxygen is maintained at about 5 to 5.5% (15 to 20% excess air).

3. Although the bio-oil flow rate is increased, the airflow required to maintain effective combustion is similar to that for the petroleum-based fuels.
4. The exhaust gases from bio-oil have a higher content of water vapor resulting in a slightly higher dew point for the stack gases, but values are well below normal boiler exhaust temperatures.
5. Composition of the flue gas shows higher CO_2 levels from the bio-oil with CO and NO levels between those for #2 and #6 fuel oils. TSP emissions are close to those for #2 fuel oil and lower than those for burning #6 fuel oil. The bio-oil SO_2 levels are dramatically lower than those for petroleum-based fuels. At lower bio-oil flow rates, i.e. lower heat transfer rates, and lower flame temperatures, NO emissions are substantially reduced. At comparable flow rates for bio-oil and #2 fuel oil the NO emission is reduced by approximately 50%.
6. Emissions are influenced by the quality of the bio-oil, in particular the char/ash content and by the bio-oil contaminants, which are dictated by the composition of the biomass feedstock from which the bio-oil was produced.
7. A significant destruction of dioxins/furans occurs during combustion (up to 99%).
8. It is reasonable to expect that combustion systems for fuel oils can be converted to use a reasonable quality of bio-oil without producing emission levels that would prevent permitting in normal situations.

K. The quality of char produced is dependent on the feedstock. Whole tree chips of either hard or soft wood and/or a mixture results in a high quality char product. The char is typically used in the process as a fuel for drying the feedstock. If drier feedstocks are available and/or alternative fuels are available to operate the pyrolysis process, the char can be sold as a high quality fuel (i.e. charcoal briquettes) and/or converted into activated carbon.

L. The gas produced by pyrolysis is used in the process as a fuel and as the carrier gas. The LHV for the gas is approximately 7.7MJ/kg. The use of pyrolysis gases as a synthesis gas to produce higher value products would require extensive reforming. Due to the unfavorable economy of scale, it probably will not be feasible to use pyrolysis gas as a synthesis gas.

III. How is Bio-oil Produced: Pyrolysis Process

A. All fast pyrolysis applications in North America use some form of a fluidized bed reactor.[8,12,15] Pyrolysis typically occurs at 500^0C or less in an oxygen-free atmosphere resulting in essentially the destructive distillation of chemicals from the wood. The process is kept at low temperatures to minimize decomposition

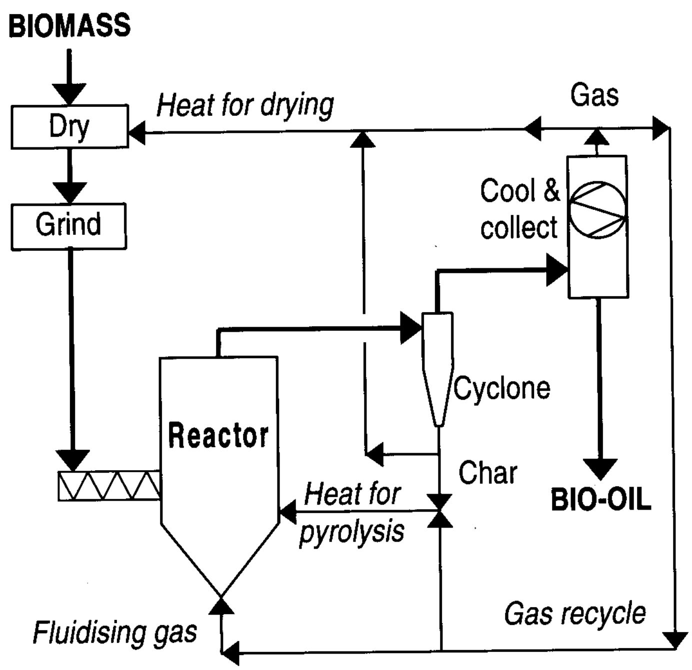

Figure I. Conceptual fluid bed fast pyrolysis process [12]

(i.e. increase the amount of oil product) and therefore minimize the production of hazardous chemicals such as dioxins and furans.[13]

B. Essential features of the fast pyrolysis process are:

1. Very high heating and heat transfer rates which require the moisture content of the feedstock to be 5-8% and feedstock to be finely ground to a particle size of approximately 2mm.
2. Carefully controlled pyrolysis reaction temperatures of approximately 500^0C in the vapor phase with short vapor residence times of typically less than 2 seconds.
3. Rapid cooling of the pyrolysis vapors to recover the bio-oil product.

IV. Companies Utilizing Fast Pyrolysis

There are three companies in North America utilizing fast pyrolysis to produce bio-oil and other related products. These are Ensyn Technologies, Inc. (Ensyn), DynaMotive Energy Systems Corporation (DynaMotive) and Renewable Oil International (ROI).

A. Ensyn Technologies, Inc.[3,23]

1. Is the oldest of the three companies having been in existence since 1984.
2. Is based in Ottawa, Ontario, Canada with its parent company Ensyn Group, Inc. located in Boston, MA.
3. Utilizes Rapid Thermal Processing (RTP™)[24] technology or transported bed in which a continuous stream of hot sand supplies the heat required to rapidly vaporize the wood feedstock.
4. Is the only company with an existing commercial process, which has been in operation since 1989.
5. Currently have six (6) commercial plants the largest of which processes 45 tons per day of dry wood for production of food flavorings and by-product energy. Residual bio-oil and char are being used for process and facility heat as well as for producing electricity
6. Business philosophy is to control their business by maintaining patented and proprietary technology. Ensyn will manage and operate facilities owned by the Ensyn Group or as a partner in joint ventures with other business partners and/or investor groups.
7. Is promoting a bio-refinery approach analogous to a petroleum refinery where raw bio-oil and solid carbon products are produced from low-grade wood. The bio-oil and carbon are then refined to produce a broad spectrum of value-added fuel, chemical and carbon products. The products include resins, polymers, emulsifiers, food flavorings and activated carbon as well as heat and power produced from the residual bio-oil from the refinery process.
8. As discussed above, the products are renewable, greenhouse gas-neutral, extremely low in sulfur content and replace products from non-renewable petroleum resources.
9. Is the only rapid pyrolysis company to maintain its own R&D laboratory, which explores a wide variety of new applications and products from a diverse range of renewable feedstocks. This facility houses two RTP™ pilot units.
10. Examples of commercial products include
    i. NR, a natural resin ingredient used as a substitute for phenol and formaldehyde in wood panels
    ii. V-Additive, a binder-emulsifier used in the non-wood construction industry
    iii. Food additives and products including flavorings, browning agents and activated carbons for de-colorization
    iv. Bio-fuels such as solid charcoal and liquid fuels
    v. Green power, with electricity generated using the bio-oil products

10. Ensyn is constructing a new 50,000 sq.ft. facility in Renfrew, Ontario, Canada to house a new bio-refinery, which will be capable of processing 60 tons of dry feedstock per day. This will be the first RTP™ facility to integrate the production of multiple commercial products with electricity generation.

B. DynaMotive Technologies Corp.[4,25]

1. DynaMotive was incorporated in 1991 and is located in Vancouver, British Columbia, Canada.
2. DynaMotive is using a patented BioTherm™ process[26], which was acquired from Resource Transforms International (RTI) in February 2000. The BioTherm process utilizes a deep bubbling sand fluidized bed technology combined with a novel bio-oil recovery system. Depending on feedstock the process produces 60-75% liquid bio-oil, 10-20% solid char and 10-20% non-condensable gas. The char is used as a fuel for drying the feedstock and the non-condensed gas is recycled and used to heat the fluid bed and as the fluidizing gas.
3. Bio-oil composition is 20-25% water, 25-30% water insoluble pyrolytic lignin, 5-12% organic acids, 5-10% non-polar hydrocarbons, 5-10% anhydrosugars and 10-25% other oxygenated compounds.
4. DynaMotive built a 0.5-tpd prototype in 1997, which was upgraded in 1998 to a 2-tpd pilot facility, which was operated for over 3,000 hours. In 2001 a 10-tpd pilot plant was commissioned which has a production capacity of 6,000 liters of bio-oil per day.
5. DynaMotive expects to commission its first two commercial plants in 2004. The first will be a 2.5 MW cogeneration plant to be located at the Erie Flooring and Wood Products facility in West Lorne, Ontario. Magellan Aerospace Corporation – Orenda Division will provide the direct-fired gas turbine. A second project with a processing capacity of up to 200 green tons per day has been announced, however, the plant location has not been released. This project is supported by Technology Partnerships Canada.
6. The company's business strategy is to be an energy solutions / energy service provider. Revenues will be generated from project opportunities through technology license fees, design/engineering fees, bio-oil /char royalties and/or project equity participation. To achieve these goals DynaMotive has entered into an agreement with RTI to acquire exclusive worldwide patent rights to the BioTherm technology; is working with Orenda Aerospace, a subsidiary of the Magellan Aerospace Corporation to develop a bio-oil fueled commercial micro turbine package to produce electricity by the direct firing of bio-oil[15,27]; and has formed a strategic alliance with TECNA S.A. which allows DynaMotive to access Tecna's global design engineering expertise for plant design and construction.

7. To date DynaMotive has conducted several combustion tests of its bio-oil product, however, no commercial projects have been announced. The Canadian Government and other investors have provided financial support.

C. Renewable Oil International[5,28]

1. ROI is a small two-person start-up operation located in Florence, AL USA and Ottawa, Ontario, Canada.
2. ROI's patent pending process uses a specially designed, indirectly heated auger. Proposed advantages are that the process does not require an inert gas stream to fluidize a bed or transport hot sand. Elimination of the recycle blower and the associated heat load is reported to greatly reduce the capital and operating costs for the ROI process.
3. ROI's business approach is to develop a low cost, transportable reactor to be located in areas where there are limited feedstocks and/or integrated into operations with limited waste biomass for feedstock but sufficient to produce enough bio-oil for process heat and electrical generation.
4. To date emphasis has been on agricultural waste as a feedstock. A demo facility has been constructed using chicken liter as a feedstock. It has been reported that ROI is currently negotiating with a wood flooring company in Massachusetts to install a plant utilizing sawdust residue to produce process heat and onsite electricity.

V. Economic Variables

A. Variables affecting operating cost of a bio-oil facility include:

1. Plant Size: The largest commercial plant currently in operation is 45 tpd (plant size is based on dry tons). Ensyn has a 60-tpd facility under construction while Dynamotive has completed engineering plans for a 100-tpd plant. Consensus is that any plant over 100 tpd would be modular in design (i.e. multiples of smaller pyrolysis units operating in parallel). For this study a 100-tpd plant will be considered.
2. Plant Availability: It is assumed that the plant will operate 330 days per year thus representing 90% availability.
3. Facility Cost: Dynamotive has estimated facility costs of $2.6MM, $5.6MM, $8.2MM and $12.6MM for 25, 100, 200 and 400 tpd plants respectfully.[25] Ensyn has estimated capital costs for a 45 tpd plant to be approximately $2.5MM. Assuming reasonable cost for site preparation, construction cost, etc., it is estimated that the overall cost for an Ensyn facility would be approximately the same as that for Dynamotive. ROI has estimated the cost of capital for a 100-tpd facility to be $375,000 per year. Assuming terms of 15 years at 7% with a 20% equity investment,

this would represent a facility cost of approximately $4.2MM. The reduced facility cost for an ROI installation reflects the difference in technology, i.e. use of indirectly heated auger design.

For this study the more conventional fluidized bed design utilized by Dynamotive and Ensyn with an estimated facility cost of $ 5.6MM will be used. Assuming 20% equity investment and borrowing of $4.48MM over a period of 15 years at an average interest rate of 7%, the annual debt payment (principal and interest) will be approximately $500,000. For a 100-tpd plant, capital cost would account for approximately 15% of the annual operating cost of the facility.

4. Feedstock: Composition and moisture content of the feedstock affects both operating cost and product distribution, thus directly affecting profitability.

    a) Composition of the feedstock can vary from whole tree (white wood) chips to a blend of white wood and bark (nominally 60% white wood and 40% bark). Product distribution will vary from 66% oil, 21% char and 13% gas for a blend of white wood and bark, to 72% oil, 15% char and 13% gas for whole tree chips. Although whole tree chips increase oil production by approximately 10%, this must be offset by an increased cost for whole tree chips of approximately 25%.

    b) Moisture content for a 60/40 blend of chips is approximately 44% as compared to 38% for whole green tree chips[‡]. Thus a 60/40 blend would require an additional 8,000-ton per year of chips plus the increased cost to remove an additional 6% of moisture.

    c) Cost: Currently Whitefield Power & Light is paying $23 per ton for whole green tree chips on the open market.[29] It is assumed that a long-term contract could be negotiated for $18 per green ton. For this study it is assumed that whole tree chips at a cost of $18 per green ton will be used. At $18/t feedstock would be the greatest cost factor representing 25% annually.

5. Electricity Consumed: Based on a plant layout as presented above, it is estimated that a bio-oil plant will consume approximately 7.75M kWh of electricity per year. At a cost of 7.2 cents per kWh the cost of electricity would represent approximately 17% of the annual operating cost. Electricity costs are based on the current Public Service of New Hampshire (PSNH) rate structure as presented in Table III.[30]

6. Labor Cost: It is assumed that the plant will operate 24 hours a day, seven days a week with 8-hour shifts. This will require 16 full time

[‡] Moisture content will vary based on various factors including type of wood, location, harvest season, length of storage, etc. For this report it is assumed that the average moisture content for whole wood chips at time of consumption is 38%. The chips will be dried to 8% moisture content, thus removing approximately 80% of the moisture. The moisture content will vary based on local conditions.

Total Use	Monthly	Annual
	645,833	7,750,000
Monthly Charges		
Energy	$ 30,160.42	
Customer Charge	$ 319.43	
Systems Benefit	$ 1,937.50	
Electricity Consumption Tax	$ 35.52	
Off-peak	$ 7,544.63	
On-peak - first 150 kWh	$ 5.63	
On-peak - all other	$ 6,400.36	
Total	$ 46,403.49	$ 556,842
Cost per kWh		$ 0.072

Table III. Electric use for a bio-oil facility using PSNH rate structure.

hourly employees at an average annual salary of $31,200 for plant operations. In addition, G&A will require one salaried manager, $62,500 annually, and 1.5 full-time equivalent hourly staff at $31,200 annually. A labor overhead rate of 20% is assumed. Labor cost will represent 22% of the annual operating expense.

7. Royalty / License Fee: A royalty / license fee of 3% of total revenue is assumed.
8. Other assumptions and conversion factors are given in Table IV.

VI. Pro Forma Income Statement for a stand alone bio-oil facility

A. Factors affecting income include the following:

1. Heat Content: The heat content of bio-oil is approximately 55% that of #2 fuel oil. To obtain the same energy release as that of oil it would take 1.82 times more bio-oil.
2. Price Per Gallon: The consumer tank car price for #2 fuel oil on October 29, 2003 at port of New York was $0.86 per gallon.[31] The bio-oil cost equivalent would be $0.47 per gallon. Assuming operating cost as stated above, a bio-oil facility would generate a loss of approximately $970,000 annually (Table V). The breakeven price would be $0.71.
3. To attract a serious investor and bank financing, it is assumed that a bio-oil plant would need to generate a minimum 20% return on investment (ROI). A 20% ROI would require a bio-oil sale price of $0.76 per gallon. See Table VI.

Item	Amount
Plant Size	100 tpd
Plant Availability	90%, 330 days/yr
Raw Feedstock Consumed	45,540 green t/yr
Feedstock Cost	$ 18/green ton
Feedstock Composition	Whole Wood Chips
Moisture Content	38%
Bio-oil Yield	72%
Bio-oil Production	4,752,000 gal/yr
Bio-oil Yield per ton	200 gal/t bio-oil
Bio-oil Heat Content	75,500 btu/gal
Cost of #2 Fuel Oil	$ 0.86
Density Bio-oil	1.2 kg/l - 10.04 lbs/gal
Char Yield	15%
Char Production	4,950 t/yr
Plant Capital Cost	$ 5.6MM
Equity	20%
Debt Financed	$4.48MM
Return on Investment (ROI)	20%
Debt Amortization	15yr
Finance Rate	7%
Electricity Consumed	7,750,000 kWh
Cost of Electricity	$0.072/kWh
Labor Rate (Hourly)	$31,200/yr
Labor Rate (Salaried)	$62,500/yr
Production Staff	16
G&A Staff	1 (Salaried) 1.5 fte (hourly)
Overhead Rate	20%
Process Heat	Bio-gas and Bio-oil for pyrolysis heat Char for dryer heat
Bio-Oil Consumed	6%
Char Consumed	31%
Maintenance Cost (%Capital)	5%
Consumables (%Sales)	5%
Royalty / License Fee (% Sales)	3%

Table IV. Assumptions and Conversion Factors Used in Financial Calculation

Stand Alone Bio-Oil Plant				
Net Sales				
Bio-oil	$	2,099,434		
Char	$	159,924		
Electricity		-		
Chemicals		-		
Total Sales			$ 2,259357	
Cost of Goods Sold				
Labor & Overhead	$	599,040		19%
Feedstock	$	819,720		25%
Electricity	$	556,838		17%
Consumables	$	112,968		4%
Maintenance	$	280,000		9%
Total CGS			$ 2,368,565	
Gross Profit / (Loss)			$ (109,208)	
Operating Expenses				
SG&A	$	131,160		4%
Cost of Money	$	491,880		15%
Royalty	$	67,781		2%
Property Tax	$	168,000		5%
Total Operating Expense			$ 858,821	
Net Profit / (Loss)			$ (968,029)	
Break Even Bio-oil Price	$	0.71 /gal		
Break Even Electricity Price	$	- /kWh		
Break Even Chemical Price	$	- /lb		
20% ROI Bio-oil Price	$	0.76 /gal		
Assumptions				
Feedstock	$	18 /ton		
Bio-oil Sale Price	$	0.47 /gal		
Price of # 2 Fuel Oil	$	0.86 /gal		
Char Sales Price	$	47 /ton		
Electricity Sale Price	$	- /kWh		
Chemicals Sale Price	$	- /lb		

Table V. Pro Forma Income Statement for a Stand Alone Bio-oil Plant
Bio-oil Sale Price $0.47 per gallon

Stand Alone Bio-Oil Plant						
Net Sales						
Bio-oil	$	3,394,829				
Char	$	159,924				
Electricity		-				
Chemicals		-				
Total Sales				$	3,554,752	
Cost of Goods Sold						
Labor & Overhead	$	599,040				18%
Feedstock	$	819,720				25%
Electricity	$	556,838				17%
Consumables	$	177,738				5%
Maintenance	$	280,000				8%
Total CGS				$	2,433,335	
Gross Profit / (Loss)				$	1,121,417	
Operating Expenses						
SG&A	$	131,160				4%
Cost of Money	$	491,880				15%
Royalty	$	106,643				2%
Property Tax	$	168,000				5%
Total Operating Expense				$	897,682	
Net Profit / (Loss)				$	223,735	
Break Even Bio-oil Price	$	0.71	/gal			
Break Even Electricity Price	$	-	/kWh			
Break Even Chemical Price	$	-	/lb			
20% ROI Bio-oil Price	$	0.76	/gal			
Assumptions						
Feedstock	$	18	/ton			
Bio-oil Sale Price	$	0.76	/gal			
Char Sales Price	$	47	/ton			
Electricity Sale Price	$	-	/kWh			
Chemicals Sale Price	$	-	/lb			

Table VI. Pro Forma Income Statement for a Stand Alone Bio-oil Plant

4. To achieve a 20% ROI, one or more of the following would be needed:

a) The price paid for feedstock is lowered to $2.50 per ton.

b) Sell to customers with lower oil consumption, i.e. those who do not buy at tank car prices. Irving Oil's 2003 contract price to small business in the Littleton, NH area ranged from $1.10 to $1.29 per gallon. Assuming $0.05 per gallon delivery cost, the equivalent price for a gallon of bio-oil would be $0.63 - $0.74 per gallon.

c) Reduce operating cost: Co-locating the bio-oil plant with an existing power plant such as Whitefield Power & Light could lower operating cost. Savings of approximately $768,000 are estimated as follows:

(1) By sharing the existing wood handling facilities, capital equipment needs can be reduced by an estimated $800,000, thus reducing the cost of money approximately $90,000 annually.

(2) Co-sharing of labor could reduce savings by approximately $365,000 annually.

(3) Utilization of waste heat from the power plant rather than using char and bio-oil to dry the feedstock, thus allowing all of the char and bio-oil produced to be sold. This would result in increased sales of approximately $240,000 annually.

(4) Assuming electricity could be purchased directly from the plant at a savings of $0.008 /kWh would result in a savings of approximately $73,000 annually.

(5) By co-locating with an existing wood fired power plant and selling bio-oil to a mix of customers at an average sales price of $0.55 per gallon a 20% ROI could potentially be achieved. See Table VII.

VII. Alternative Plant Configurations: Combined Bio-oil / Electric Generating Plant.

A. Power generating plant utilizing a direct-fired gas turbine.

1. Operating Cost: Capital cost to include a direct-fired gas turbine and equipment necessary to connect to the grid would cost an additional $3M.[32] This would require an additional $600,000 in equity and an additional $265,000 in cost of money annually. The proposed turbine would generate 2.5 MW of electricity and consume approximately 75% of the bio-oil generated.[27]

Bio-Oil Plant Co-Located with Wood Fired Power Plant

Net Sales					
Bio-oil	$	2,613,600			
Char	$	232,650			
Electricity		-			
Chemicals		-			
Total Sales			$	2,846,250	
Cost of Goods Sold					
Labor & Overhead	$	299,520			11%
Feedstock	$	819,720			31%
Electricity	$	426,250			16%
Consumables	$	142,313			5%
Maintenance	$	240,000			9%
Total CGS			$	1,927,803	
Gross Profit / (Loss)			$	918,448	
Operating Expenses					
SG&A	$	65,580			2%
Cost of Money	$	421,611			16%
Royalty		85,387.50			3%
Property Tax	$	144,000			5%
Total Operating Expense			$	716,579	
Net Profit / (Loss)			$	201,869	
Break Even Bio-oil Price	$	0.50	/gal		
Break Even Electricity Price		-	/kWh		
Break Even Chemical Price		-	/lb		
20% ROI Bio-oil Price	$	0.55	/gal		

Assumptions			
Feedstock	$	18	/ton
Bio-oil Sale Price	$	0.55	/gal
Char Sales Price	$	47	/ton
Electricity Sale Price		-	/kWh
Chemicals Sale Price		-	/lb

Table VII. Pro forma Income Statement For Bio-oil Plant Co-Located with Wood Fired Power Plant

2. Profitability: Assuming the current price paid for electricity on the open market to be \$0.03959 /kWh* there would be an operating loss of approximately \$1.82M annually. The breakeven price would be \$0.123/kWh and to achieve 20% ROI would require \$0.138/ kWh. See Table VIII.

3. Energy Credits: There are numerous state and federal bills being considered to provide credits for producing "clean electricity".[33] These include CO_2, SO_2, NO_x and renewable portfolio standards (RPS). To date Connecticut, Massachusetts, and Rhode Island have enacted an RPS standard. With all of these measures becoming reality one can envision an additional 4-7 cents /kWh. This support is not a certainty and if enacted would be several years before the effects would be completely realized. The assumption is that one cannot rely on energy credits at this time.

B. Convert an existing wood fired plant to burn bio-oil.

1. Converting the boiler to burn bio-oil would be less expensive; however, the existing steam turbine at the wood fired power plant is rated at 16 MW. Operating the turbine off peak would not be cost-effective. To fully utilize the existing steam turbine would require scaling the bio-oil plant to 250 tpd. This option is outside the scope of this study.
2. Another alternative would be to eliminate both the existing wood fired boiler and steam turbine, replacing them with a 2.5 MW direct-fired gas turbine. This option is also considered to be outside the scope of this study.

VIII. Alternative Plant Considerations: Bio-oil Refinery

A. Existing commercial bio-oil plants are considered bio-refineries in that higher value added products are "refined" from the bio-oil. The residual bio-oil is then used in a combined cycle application to produce process heat and/or generate electricity via a steam turbine. An example of this is the Ensyn plant operated by Red Arrow in which food flavorings are extracted from the bio-oil and the residual bio-oil is used to generate process heat for the Red Arrow plant. Ensyn's new plant under construction in Renfrew, Ontario will presumably produce a phenolic resin for the fiberboard industry and the residual bio-oil will be used to produce electricity. Cost considerations for a bio-refinery are as follows:

1. The basic pyrolysis operation is the same as discussed for a stand-alone plant. In addition, one must add the additional expense of the

* Whitefield Power & Light reported that the average monthly energy clearing price, May 1999 – February 2003 was \$0.03959/ kWh. WP&L estimates their break-even cost, which includes their current cost of feedstock to be \$0.045/ kWh.

Bio-Oil Power Generating Plant				
Net Sales				
Bio-oil	$ 614,196			
Char	$ 159,924			
Electricity	$ 867,021			
Chemicals	-			
Total Sales			$ 1,641,141	
Cost of Goods Sold				
Labor & Overhead		$ 599,040		17%
Feedstock		$ 819,720		24%
Electricity		$ 322,164		9%
Consumables		$ 82,057		2%
Maintenance		$ 430,000		12%
Total CGS			$ 2,252,981	
Gross Profit / (Loss)			$ (611,840)	
Operating Expenses				
SG&A		$ 131,160		4%
Cost of Money		$ 755,387		22%
Royalty		$ 49,234		1%
Property Tax		$ 258,000		7%
Total Operating Expense			$ 1,193,781	
Net Profit / (Loss)			$ (1,805,621)	
Break Even Bio-oil Price	$	-	/gal	
Break Even Electricity Price	$	0.122	/kWh	
Break Even Chemical Price	$	-	/lb	
20% ROI Electricity Price	$	0.138	/kWh	

Assumptions			
Feedstock	$	18	/ton
Bio-oil Sale Price	$	0.55	/gal
Char Sales Price	$	47.00	/ton
Electricity Sale Price	$	0.040	/kWh
Chemicals Sale Price	$	-	/lb

Table VIII. Pro forma Income Statement for a combined Bio-oil / Electric Generating Plant.

refinery operation. Actual configuration and cost of the refinery are proprietary; however, from discussions with Ensyn management it is estimated that capital equipment cost would be approximately $1MM with a total installation cost of approximately $2MM. Operating costs have been adjusted proportionally.

2. Chemical Extraction: A 25% reduction in bio-oil production is assumed when chemicals are extracted. This is consistent with analysis showing that typically 30% of the bio-oil recovered is a so-called phenolic/neutral fraction. It is estimated that this phenolic fraction will yield approximately 12% by weight phenolic resin. For a 100-tpd plant this represents a production of approximately 1.6 million pounds of phenolic resin annually. In a paper by Dr. Esteban Chornet it is reported that the value of such lignin-derived chemicals is $3.00 per kg ($1.36 per lb).[31] The price of charcoal is reported as $120 per tonne ($109 per ton).Using these prices the income from the sale of resins and charcoal would be approximately $2.18MM and $0.371MM annually. A pro forma income statement based on the above assumptions is presented in Table IX.

IX. Co- Location of a Bio-Refinery with an Existing Wood Fired Power Plant

A. Economically, the best configuration would be to co-locate a bio-refinery with an existing wood fired power plant. A pro forma income statement is presented in Table X.

B. Selling bio-oil at $0.55 a gallon, char at $109 per ton and chemicals at $1.36 a pound, a net profit of approximately $1.12MM annually could be realized. Reducing the sales price of chemicals to $0.85 per pound or jointly reducing the sales price of char and chemicals to $47/ton and $0.97/lb respectively would still provide a 20% ROI.

IX. References

[1a] Innovative Natural Resource Solutions LLC and Draper Lennon, Inc. *Identifying and Implementing Alternatives to Sustain the Wood-Fired Electricity Generating Industry in New Hampshire.* Prepared for the NH Department of Resources and Economic Development. January 2002.

[1b] Innovative Natural Resource Solutions LLC and Draper Lennon, Inc. *Use of Low Grade and Underutilized Wood Resources in New Hampshire.* Prepared for the NH Department of Resources and Economic Development. February 2001.

Stand Alone Bio-Refinery					
Net Sales					
Bio-oil	$	1,719,749			
Char	$	370,887			
Electricity	$	-			
Chemicals	$	2,177,435			
Total Sales			$	4,268,070	
Cost of Goods Sold					
Labor & Overhead	$	599,040			16%
Feedstock	$	819,720			21%
Electricity	$	612,521			16%
Consumables	$	213,404			6%
Maintenance	$	380,000			10%
Total CGS			$	2,624,685	
Gross Profit / (Loss)			$	1,643,385	
Operating Expenses					
SG&A	$	206,160			5%
Cost of Money	$	667,551			17%
Royalty	$	128,042			3%
Property Tax	$	228,000			6%
Total Operating Expense			$	1,229,753	
Net Profit / (Loss)			$	413,632	
Break Even Bio-oil Price	$	0.55	/gal		
Break Even Electricity Price	$	-	/kWh		
Break Even Chemical Price	$	1.10	/lb		
20% ROI Chemical Price	$	1.29	/lb		
Assumptions					
Feedstock	$	18	/ton		
Bio-oil Sale Price	$	0.55	/gal		
Char Sales Price	$	109	/ton		
Electricity Sale Price	$	-	/kWh		
Chemicals Sale Price	$	1.36	/lb		

Table IX. Pro forma Income Statement for a Bio-Refinery

Bio-Refinery Co-Located with Wood Fired Plant				
Net Sales				
Bio-oil	$ 1,719,749			
Char	$ 370,887			
Electricity	$ -			
Chemicals	$ 2,177,435			
Total Sales			$ 4,268,070	
Cost of Goods Sold				
Labor & Overhead	$ 299,520			9%
Feedstock	$ 819,720			26%
Electricity	$ 468,875			15%
Consumables	$ 213,404			7%
Maintenance	$ 340,000			11%
Total CGS			$ 2,141,519	
Gross Profit / (Loss)			$ 2,126,552	
Operating Expenses				
SG&A	$ 103,080			3%
Cost of Money	$ 597,283			19%
Royalty	$ 128,042			4%
Property Tax	$ 204,000			6%
Total Operating Expense			$ 1,032,405	
Net Profit / (Loss)			$ 1,094,147	
Break Even Bio-oil Price	$ -	/gal		
Break Even Electricity Price	$ -	/kWh		
Break Even Chemical Price	$ 0.68	/lb		
20% ROI Bio-oil Price	$ 0.87	/lb		
Assumptions				
Feedstock	$ 18	/ton		
Bio-oil Sale Price	$ 0.55	/gal		
Char Sales Price	$ 109	/ton		
Electricity Sale Price	$ -	/kWh		
Chemicals Sale Price	$ 1.36	/lb		

Table X. Pro forma Income Statement For Bio-Refinery Co-Located with Wood Fired Power Plant

[2] Innovative Natural Resource Solutions LLC. *Markets for Low-Grade Wood in New Hampshire.* Prepared for the Governor's Office of Energy and Planning. January 2004. and references therein.

[3] Ensyn Technologies, Inc. web site, www.ensyn.com

[4] DynaMotive Energy Systems Corporation web site, www.dynamotive.com

[5] Renewable Oil International web site, www.renewableoil.com

[6] Innovative Natural Resource Solutions LLC. *Feedstock Availability and Pricing.* Prepared for the New Hampshire Office of Energy and Planning. January 2004. and references therein.

[7] Letter from the NH Division of Forests & Lands on House Bill 787 to Rep. John Thomas, Chair, NH House Committee on Science, Technology and Energy. March 5, 2003.

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[18] Sturzl, Ray. *The Commercial Co-Firing of RTP™ Bio-Oil at the Manitowoc Public Utilities Power Generating Station.* June 1997.

[19] Ensyn Technologies Inc. *Boiler Performance and Emission Compliance of Pyrolysis Oils.* Prepared for Natural Resources Canada, Ottawa, Ontario. Catalogue No. M91-7/424-1997E. October 1995.

[20] Wong, J.K.L., Banks, G.N. and Whaley, H. *Flame Tunnel Emissions Testing of ENSYN Liquid Bio-Fuels.* Canada Centre for Mineral and Energy Technology. May 1995.

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X. Appendix I

The attached CD contains a folder entitled *Pro Forma Income Calculations.* This is an Excel Spreadsheet with all of the financial assumptions and conversion terms as well as calculations for all plant configurations considered in this report. Using this spread sheet, recipients will be able to make their own assumptions by changing the input parameters and thus assess the financial impact of these changes on the various plant options considered herein.